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ABSTRACT

This three-section report provides introductory information about biogas production and its application to farm environments. The first section discusses the various components of a biogas production system (a system that converts organic wastes into a usable form of energy), explains the system's benefits and liabilities, and provides a brief checklist to determine if biogas production may be applicable to a specific situation. The second section features descriptions of four biogas projects using a case study approach. These projects were completed with federal funds awarded to farmers, ranchers, and engineers to design, construct, and demonstrate biogas production systems. The third and final section provides descriptions of several Department of Energy grants relating to biogas production and an annotated list of suggested readings. (ML)

AN INTRODUCTION TO BIOGAS PRODUCTION ON THE FARM

Prepared for:
U.S. Department of Energy
Assistant Secretary, Conservation and Renewable Energy
Small Scale Technology Branch
Appropriate Technology Program
Under Contract No. DE-AC01-82CE15095

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PREFACE

From 1978 to 1981, the U.S. Department of Energy (DOE) awarded more than 2,000 small grants to individuals, organizations and small businesses across the nation to research and demonstrate appropriate technologies. Grants were given in the general areas of conservation, solar, biomass, wind, geothermal and hydropower.

This booklet is part of a series of publications that focuses on new ideas for appropriate technologies and their application in the home and workplace. These publications combine a qualitative assessment of the results of grant projects with current research for the particular technology highlighted in this document. Included in Section III of this publication is a list of the pertinent projects reviewed in preparation of the document.

INTRODUCTION

American farmers, known for their resourcefulness and ingenuity, are turning to various appropriate technologies to combat increasing fuel costs. Using insulation, energy management techniques, and energy saving equipment, farmers are effectively conserving energy; others are turning to the wind, the sun, or to streams on their land to generate the energy consumed on their farms. Still others are looking even further in their attempts to find ways to maintain the productivity and competitiveness of their farms and ranches in light of high energy costs. They are looking at the wastes produced in their operations and devising systems that not only dispose of this waste in a cost-effective manner, but actually produce energy in the process. Biogas production is one of these systems.

Biogas production, which converts organic wastes into a usable form of energy, is not a new technology. For decades farmers in Europe and Asia have been using this technology to recycle wastes. But until recently there has been little interest in the United States, primarily because of the availability of inexpensive energy and chemical fertilizers. But as the costs of operating a farm and disposing of its wastes increase, interest in biogas production has also grown.

Biogas can be produced from any organic material, or "feedstock" as it is known. Manure, for example, is an ideal feedstock because it requires only minimal processing, is readily broken down in the biogas-producing process and, most importantly, processing it into biogas solves an often difficult disposal problem. Once processed, the only end products are a usable gas and a nutrient-rich fertilizer.

A number of farmers, ranchers, and engineers received support from the U.S. Department of Energy Appropriate Technology Small Grants Program to design, construct, and demonstrate biogas production systems. Many of these projects generated more than just biogas; grantees' work and results have contributed to a growing body of information about practical applications of this technology.

This publication was developed to share some of that information, to answer the basic questions about biogas production, and to lead farmers to more information. Section I introduces biogas and the various components of a biogas production system, discusses the system's benefits and liabilities, and provides a brief checklist to determine if biogas production may be applicable to an individual's particular situation. Section II features descriptions of four biogas projects of various sizes. Section III provides sources of additional information including descriptions of other biogas production projects.

SECTION I: AN INTRODUCTION TO BIOGAS PRODUCTION

WHAT IS BIOGAS ?

Biogas is one of the products created when organic materials decompose in the absence of oxygen. This happens in nature with so-called "swamp gas"; it also happens when food is broken down in an animal's digestive system. It is possible to duplicate this digestive process and, in so doing, produce biogas.

Basically, it works like this: present within an animal's digestive system are bacteria which break down the nutrients in food; many of these bacteria survive in the animal's manure. If the manure is put into a tank which, like the digestive system, is oxygen free, these bacteria go back to work where they left off, continuing to break down the fats, carbohydrates, and proteins which were not consumed by the animal. The result is biogas, a combination of methane, carbon dioxide, and trace gases. When properly digested, the only remaining "waste" is free of harmful organisms, virtually odorless, nonpolluting and can be recycled as fertilizer, a bedding material, or even a feed additive.

The biogas produced can be used like natural gas in equipment and engines that have been properly converted. In fact, the only major difference between biogas and natural gas is their methane concentrations. Natural gas is approximately 95 percent methane, while unrefined biogas is only 50 to 70 percent methane. Since methane is the combustible portion of the gases (the other gases, predominantly carbon dioxide, do not burn), this means that natural gas contains more energy than biogas, a good thing to keep in mind when evaluating the production potential of a system.

GLOSSARY

ANAEROBIC—without, or in the absence of, oxygen.

ANAEROBIC DIGESTION—the breaking down of organic materials by bacteria in the absence of oxygen.

BIOGAS—the gaseous mixture produced by anaerobic digestion. The mixture is chiefly composed of methane (CH_4) and carbon dioxide (CO_2), in the ratio of approximately 2 to 1 (actual production rates can vary from 1 to 1 to almost 3 to 1).

BTU's—British thermal units; 1 Btu is the amount of heat necessary to raise one pound of water 1 °F.

DIGESTER—tank or covered pond which is airtight. Digesters come in many sizes, shapes and configurations, and can be made out of various materials, including metal, concrete, or plastic.

EFFLUENT—the waste drained from the digester after biogas production.

FEEDSTOCK—the organic waste "fed" to the digester (i.e., manure or plant residue).

HEAT EXCHANGERS—mechanical devices which transfer heat from one fluid to another.

METHANE—a combustible gas. Natural gas is approximately 95 percent methane; unrefined biogas is approximately 60 percent methane.

NON-POINT SOURCE POLLUTION—pollution which cannot be identified as coming from a specific source (i.e., from a smoke stack or from the discharge of a factory).

pH—a measure of relative acidity or alkalinity.

SCRUBBERS—compounds which remove unwanted gasses from the biogas such as carbon dioxide or hydrogen sulfide.

STABILIZED WASTE—waste that is free of harmful organisms; the result of anaerobic digestion.

BIOGAS PRODUCTION SYSTEM

Although each system is unique, the basic components of a biogas system are the same:

1) a manure handling system;
2) a system for mixing the manure with water (if required);
3) a digester vessel;
4) a system for controlling the temperature within the digester (if required);
5) scrubbers for removing unwanted gases from the biogas (if required);
6) a biogas collection system and storage tank;
7) a system for using the biogas; and,
8) a system for using the remaining effluent.

A description of each component follows; descriptions of specific systems are included in Section II.

1. *Manure Handling System*

Unless livestock are allowed to move over a large area of land, sufficiently dispersing the manure, some kind of manure handling system is required. Such systems vary according to the nature and size of the operation. For example, farmers and ranchers with smaller operations often manually collect and dispose of manure. For larger operations, it is necessary to streamline the collection process.

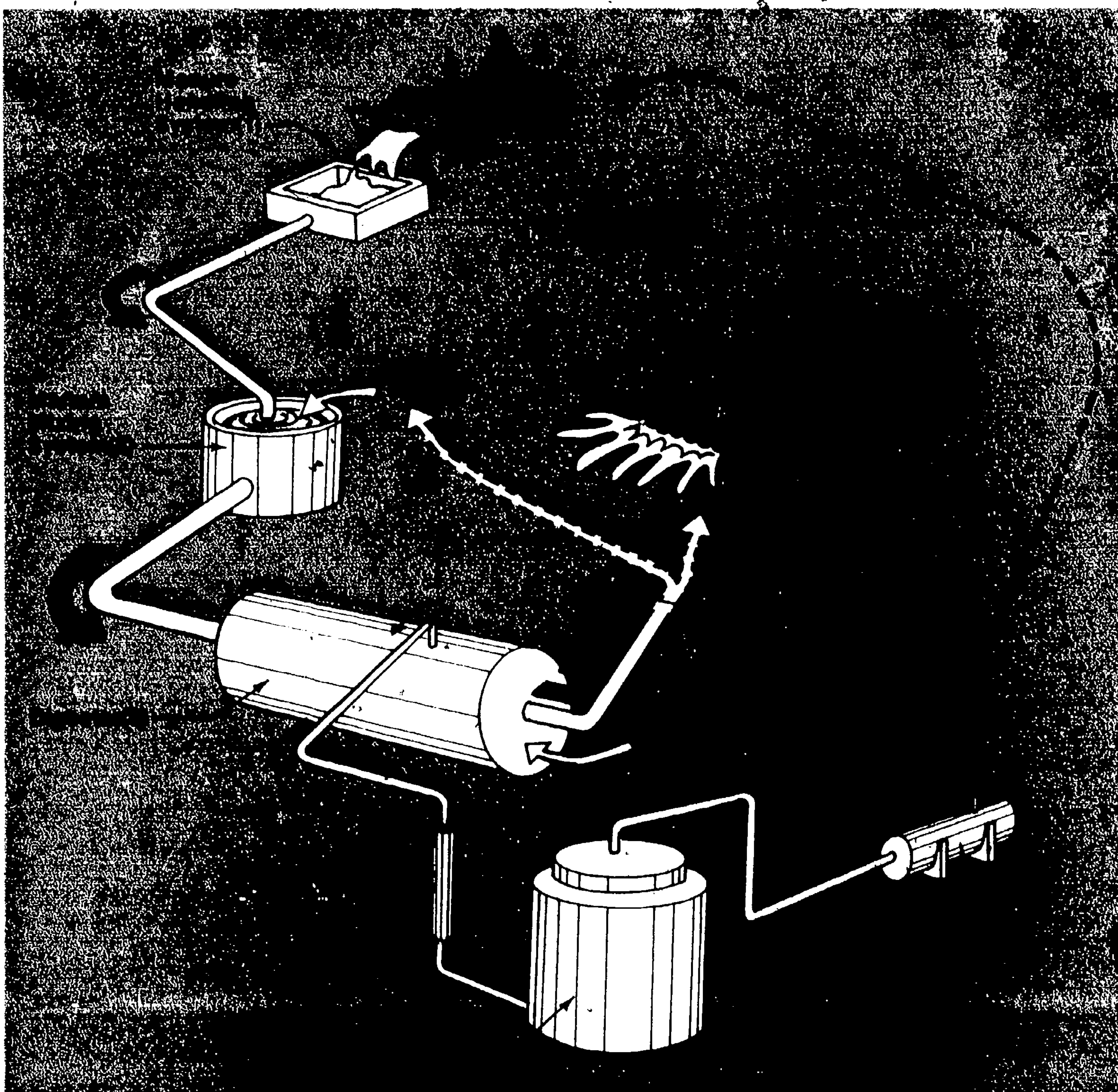
Many farms and ranches have manure handling systems that enable the operator to scrape or wash the manure into a trough at the center of the barn where it flows into a holding tank for disposal. Another option uses slatted floors which allows the manure to drop directly into the collection area; hoses and/or scrapers are then used to flush the system on a regular basis.

It is important to note that most existing manure handling systems on farms and ranches, large or s[illegible]ll, can be successfully used as part [illegible]bgas production system. The [illegible] ference is that when the m[illegible] lected, it is processed [illegible] able source of energy before it is disposed of in ponds or spread in the fields.

2. A System for Mixing the Manure with Water

Before adding manure to the digester, it must be combined with water. The right mixture of solids and liquids is necessary for several reasons: 1) it is easier to move manure from the source to the digester if it's in a semi-liquid state; 2) it helps prevent the solids from settling in the bottom of the digester; and 3) it is easier for the bacteria to break down the manure in a diluted state. Water is also added if needed to dilute the am-

FIGURE 1: *The basic components of a biogas production system.*



monia concentrations present in the animals' urine (An excess of ammonia can slow down or even prevent biogas production.) In most systems, water is either added when the manure is washed into the holding tanks or added once it is in the digester.

With some livestock, beef and dairy cattle, for example, it is often unnecessary to add water; the manure is usually at the right consistency. However, with other animals, such as chickens and turkeys, it usually takes approximately two and one half times as much water as manure to reach the proper dilution.

3 The Digester

There are two basic types of digesters that are applicable to farm-sized production of biogas: batch and continuous.

Batch Digesters. With a batch system, manure is placed in an oxygen-free tank or pond and left to ferment. Once the digestion is complete, the biogas is used, the effluent or a portion of it is removed, and the process is repeated.

Although this kind of digester can be messy and difficult to load, it can be built on a smaller scale and for less money than continuous digesters. Batching is often the best choice for individuals who have a small enough operation to allow manure to sit unattended until the digester is ready to be reloaded or who want to start producing biogas on a small scale.

Continuous Digesters. Although manure is not fed into the system continuously, with this kind of digester manure can be fed into the system on a regular basis without disrupting the biogas production. There are three kinds of continuous digesters: vertical tank, horizontal tank, or multiple tank.

Vertical tank systems use an upright, oxygen-free tank which is loaded and unloaded from the top. To operate a vertical tank system, some of the processed manure is removed and replaced with an equal amount of fresh feedstock. This new feedstock is mixed into the remaining effluent with mechanical mixers or by pumping biogas into the mixture to circulate it.

With horizontal tanks (also known as plug-flow digesters), feedstock is added at one end of the digester which displaces an equal amount of processed manure at the other end.

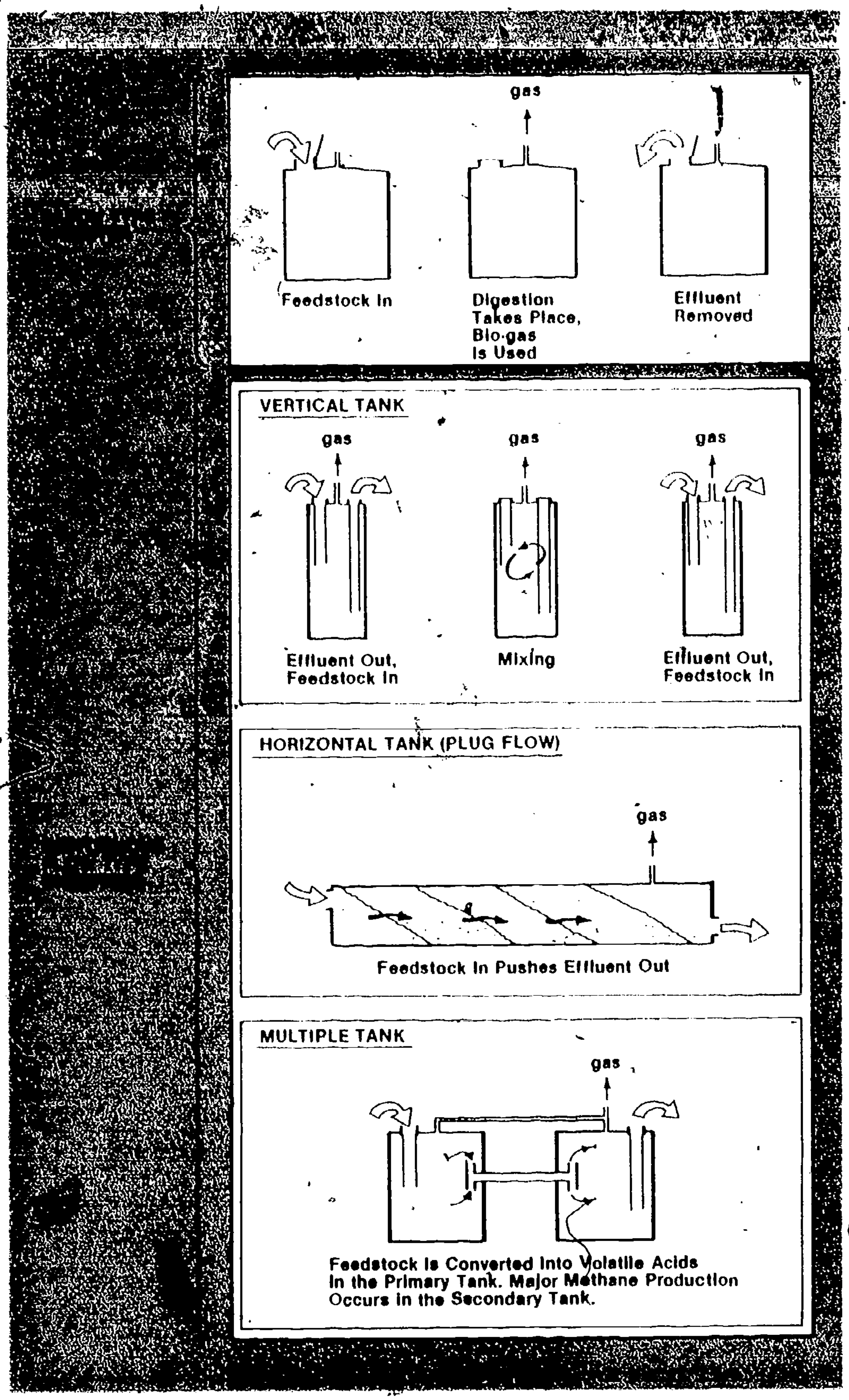


FIGURE 2: *Two basic types of digesters can be used for farm-sized biogas production: batch and continuous.*

This kind of digester works particularly well with manure that is about 10 percent solids, such as beef and dairy cattle manure. The new feedstock is generally not mixed when added to the digester because if it is overmixed in the process, the effluent flowing out the opposite end may contain undigested, bacterially contaminated materials.

With multiple-tank or phase digesters, two tanks are used to separate the biogas production process. The production of biogas occurs because of two different kinds of bacteria: the first, an acid-forming bacteria, converts the complex fats, carbohydrates, and proteins into simple compounds called volatile acids; the second, a methane-forming bacteria, converts the volatile acids into biogas. A multiple tank digestion system uses two tanks which are kept at different temperatures and pH levels to encourage the work of these different bacteria. In the first tank, the acid forming bacteria converts the bulk of the wastes into volatile acids. As new manure is fed into the system, this waste is pushed into the second tank where the cooler temperatures allow the methane-producing bacteria to work more efficiently.

This phased approach allows for higher loading rates without imbalancing the reaction that's taking place within the digester, because the acid-forming bacteria are not as sensitive to pH fluctuations as the methane-producing bacteria in the second tank. It also increases the stability of the process by allowing the acid-forming bacteria to work without inhibiting the growth of the methane-producing bacteria. The only real disadvantage of this type of system is its cost: multiple tank digesters can cost two or three times more than a similarly sized plug-flow digester.

4. Temperature Control System

Biogas can be produced at temperatures ranging from 68°F to 131°F (20-55°C), but experience has shown that small-scale farm digesters are most effective if the operating temperature is maintained at a constant 95°F.

In northern climates, particularly in the winter months, maintaining a constant operating temperature can be a problem. There are several ways to resolve this. First, the digestion process itself (much like composting or alcohol fermentation) gives off heat, so it's important that the heat be retained. The simplest way to accomplish this is to insulate the digester. It's important to note, however, that the digester should be insulated with closed-cell, foam insulation rather than insulation like fiberglass, which contains pockets of air. Should any biogas leak from the digester and mix with the air trapped in the insulation, it could cause a potentially explosive mixture to occur.

Another way to maintain the optimal temperature is to preheat the manure before it is loaded into the digester. A common technique is to use heated water to dilute the manure. The water can be heated in a number of ways, either by a biogas-powered water heater, a solar water heater, or by a heat exchanger attached to the machinery or appliance which burns the biogas.

Another technique is to add heat to the process. This can be accomplished by simply circulating warm water through flexible rubber tubing laid at the bottom of the digester or even by surrounding the digester with a shell of temperature-controlled water.

5. A System for Removing Unwanted Gases from the Biogas

Biogas can be used as is, or it can be refined to remove most of the carbon dioxide so that, like natural gas, it's approximately 90 to 95 percent methane. In most systems, the biogas is refined as it passes from the digester into the storage area. Usually this is accomplished by passing the gas through "scrubbers," a lime-water solution which removes the carbon dioxide.

Biogas also contains traces of hydrogen sulfide which can be removed by passing the gas through iron powder or filings mixed with wood chips or sawdust. Steel wool can also be used. Failure to remove the hydrogen sulfide can cause corrosion of storage tanks, gas lines, or the appliances that burn the gas.

By removing most of the carbon dioxide, the volume of the gas will be reduced by approximately 30 to 40 percent, reducing storage requirements. Also, at 90 to 95 percent methane, biogas can be burned in any natural gas-burning appliance or engine with only minor modifications.

6. Biogas Collection and Storage System

With batch systems, biogas is often collected and stored within the digester itself. This type of storage is also common if the biogas is used directly from the digester without being refined. Otherwise, the biogas is usually stored separately from the digester.

In a typical biogas storage system, the biogas is siphoned into an oxygen-free tank or bag that is positioned within a tank of water. As gas flows into the system, pressure builds which displaces the water and causes the inner tank to rise. As gas is siphoned off for use, the inner tank returns to its original position.

Another option is high pressure storage. This type of storage system is expensive because of the energy needed to compress the gas and because the tanks, similar to those used with liquid propane or compressed gas, need to be constructed of welded steel. Because of the expense, this is usually not a cost-effective option for farm-sized systems.

In all phases of biogas production, collection, and storage, it is essential that the gas does not come into contact with air. At certain concentrations (5 to 14 percent methane), biogas mixed with air can be extremely explosive. It is also important to store biogas away from internal combustion engines, exhaust systems, and all sources of sparks or flames.

7. A System for Using the Biogas Produced

Any applicance that uses natural gas can be converted to use biogas, including cook stoves, water heaters, space heaters, lamps, and internal combustion engines.

The most efficient way to use biogas is to burn it to provide heat. Most farmers have appliances such as water heaters or boilers that can be converted to burn biogas with a 60 to 80 percent efficiency. The main disadvantage to using biogas this way is that storage is usually required. This can be a particular problem if the gas is mainly used for space heating in the winter.

In cases where more gas is produced than can be efficiently used for heat, it is possible to use the biogas to generate electricity. The advantages of this kind of application are that the gas does not have to be stored and, in most cases, the utility company must buy any excess electricity you produce (per the Public Utility Regulatory Policy Act or PURPA). The main disadvantage of this end use of the gas is that engine generators are less than 25 percent efficient. This can be improved some by capturing the waste heat from the engine and using it to warm the digester, but it never reaches the overall efficiency of burning the gas for heat. Also, hooking up to the utility can be a time-consuming and even expensive process. If you're considering producing biogas to generate electricity, find out first if PURPA applies (many electrical cooperatives are not required to purchase power), what the buy-back rates will be, and what rules and regulations will apply to you (including required insurance, meters, inverters, etc.) before investing in a system.

It is also possible to compress biogas for use in tractors and automobiles, however, even compressed, it requires that the equipment be outfitted with large fuel tanks. Methane can also be liquefied, but the extremely low temperatures and high pressures necessary to liquefy methane make the process prohibitively expensive for farm use.

8. A System for Using the Remaining Effluent

Once the digestion process is complete and the biogas is drawn off, the process requires a system to use the remaining effluent. There are several ways to accomplish this: either by using the effluent "as is" or by removing the solids from the liquid and using each separately.

Like the raw manure it came from, the effluent can be spread as fertilizer on the operator's fields. But unlike raw manure, the organic nitrogen is more readily accessible to the soil. Also, the effluent is virtually odor-free, will not attract flies, and is more sanitary than raw manure since most of the harmful bacteria have been destroyed.

If desired, the solids can be separated from the liquid. Commercial separators are available or the effluent can be left in settling basins. Mechanically separated, the solids can be used as bedding material for farm animals, processed into potting soil, or reprocessed and used as a livestock feed additive. The liquid drawn off can also be used for flushing the manure handling systems, for growing algae, or for fertilizing the fields. Using the liquid as fertilizer is particularly popular because it can be spread with irrigation equipment.

However the remaining effluent is used, it is one of the final steps in a continuous cycle, allowing the methane producer to start the digestion process over again.

Biogas Production— Is It For You?

There are certainly many factors to consider before investing in a biogas production system, but these environmental and economic questions may help you determine if a system has merit on your particular ranch or farm.

Do You Have a Waste Disposal Problem?

If flies, odor, or environmental or health regulations are forcing you to clean up your livestock's waste, you are a prime candidate for a biogas production system. For example, many farmers and ranchers who have previously spread raw manure in the fields are now faced with cleaning up this "non-point source pollution." For these individuals, biogas production may be a cost-effective solution.

You may also be a good candidate if you're considering expanding the size of your herd and/or planning on upgrading your existing manure handling system. For example, if you're considering investing in a slatted floor barn or a more automatic manure collection process, the cost of adding a digester at the same time may help pay for at least part of the system.

Are You Willing to Spend the Time and Money Necessary to Install and Maintain a Biogas System?

Just because you have a manure disposal problem does not necessarily mean that you should invest in a biogas system. There are alternatives available such as ponds, storage tanks, and aerobic composting which can adequately "handle" the manure without the added costs and responsibilities required by a biogas production system.

On the other hand, if you are mechanically inclined and willing to make the extra investment in time and money, a biogas production system can be an economical addition to your operation.

Can You Use the Biogas Produced?

If your farm or ranch has several gas burning appliances that can be used as is or converted to use the biogas, then the system may be a good investment. However, if your operation uses little or no gaseous fuel, requiring additional investments in equipment to burn the gas, you may want to think twice before installing this kind of system.

How Much Biogas Can You Produce?

If you answered yes to the preceding questions, now is the time to sit down and figure out how much biogas you can produce on your farm or ranch. Table 1 will help you get a rough estimate of the biogas production potential on your farm; actual production rates will vary depending on such variables as digester design and efficiency, loading rates, animal feeds, animal age, and animal species. One thing to keep in mind when reviewing these figures is that, depending on the system's design, up to 20 to 30 percent of the biogas you produce may have to be used to operate the system such as running the pumps or heating the digester.

What Will the Biogas Be Worth to You?

Table 2 is an example of the potential fuel value of the biogas produced from a system processing manure from 50 dairy cattle. You can figure out the same information by performing the following calculations:

1. Multiply the estimated daily biogas production by its Btu content. This will give you an estimate of the number of Btu's produced per day.

2. Divide the number of Btu's per day by the Btu content of the fuel you plan to replace with biogas. This will give you the equivalent amount of fuel produced per day.

3. Multiply the equivalent amount of fuel by the price you currently pay for the fuel you're planning to replace. This will give you the approximate value of the biogas your operation is capable of producing per day.

For example: If you estimate that you can produce approximately 2,000 cubic feet of biogas per day and plan to use it in appliances currently using natural gas, your calculations would look like this:

1. 2,000 cu ft/day × 600 Btu's/cu ft = 1,200,000 Btu's/day

2. 1,200,000 Btu's/day ÷ 1,000 Btu's/cu ft = 1,200 cu ft/day

3. 1,200 cu ft/day × $5/1,000 cu ft = $6/day

Yes, But Is It a Good Investment?

Unfortunately, there is no way to estimate the cost of a biogas production system without considering the specifics of your individual operation. In the meantime, however, there are a few "rules of thumb" that can help you determine if biogas production might be worth investigating further.

For example, if you are currently spreading manure on your fields and it is not posing any environmental or health problems, a biogas production system will probably not be a good investment. This is not to say that individuals with similar disposal systems have not invested in biogas. Many have. But their motives are not purely economical. Some are motivated by the idea of energy self-sufficiency, others prefer the convenience and efficiency of liquid fertilizer as opposed to the solid manure, and some simply like the idea of producing energy from waste. But whatever the reason, these systems are not installed for their economics alone.

If, however, you must build a pond or lagoon for waste treatment due to state and/or federal environmental regulations, or are planning to upgrade your existing manure handling system for whatever reason, a biogas digester can be an economical alternative. The additional cost of a biogas digester will more than pay for itself by producing usable gas while still providing the same improvements in pollution control.

TABLE 1: *Typical Biogas Production per 1,000 Pounds of Animal Weight*

	Biogas Production cu ft/day	Biogas Btu/day[1]	Natural Gas cu ft/day[2]	Propane gal/day[3]	Electricity kWh/day[4]
Cattle					
Dairy	35	21,000	21	23	1.4
Beef	30	18,000	18	20	1.2
Hogs	29	17,400	17.4	18	1.16
Chickens					
Layers	70	42,000	[illegible]	46	2.8
Broilers	90	54,000	[illegible]	59	3.6

1. Biogas (60% methane): 600 Btu/cu ft
2. Natural Gas: 1,000 Btu/cu ft
3. Propane: 92,000 Btu/gallon
4. Electricity: 15,000 Btu/kWh generated (22% efficiency)

Note: Another factor to consider is that a portion of the gas produced (20 to [illegible]%) may have to be used to run pumps and heat the digester.

TABLE 2: *Fuel Cost Comparison [illegible]*

(50 cows × 1,000 lbs [illegible] 50,000 lbs [illegible]

Fuel	Energy Content	Equivalent [illegible]/day	[illegible]
Biogas	600 Btu/cu ft	[illegible]	[illegible]
Natural Gas	1,000 Btu/cu ft	[illegible]	[illegible]
Propane	92,000 Btu/gal	[illegible]	[illegible]
Electricity[1]	15,000 Btu/kWh	[illegible]	[illegible]
Fuel Oil	[illegible] Btu/gal	[illegible]	[illegible]

[1]Electricity: 15,000 Btu/kWh [illegible]

[2]These fuel costs [illegible]

If you already have an efficient manure collection system and/or are storing manure in ponds or tanks suitable for conversion, the small investment necessary to convert these components to a biogas production system may more than pay for itself. Or, if you're not allowed to spread raw manure on the fields and have been investing a fortune in chemical fertilizers, again the biogas production system may in fact pay for itself.

One more thing to keep in mind when considering the overall economics of a biogas production system: biogas production systems, unlike conventional manure handling systems, qualify for energy investment tax credits. When planning your biogas system, be sure to discuss federal and state tax credits with your tax accountant to determine if you are eligible and what advantages these might have to your individual tax situation.

Where Do You Go From Here?

If biogas production still seems like a viable option, the next step is to find out more about the technology. Sections II and III will provide you with an introduction to specific systems along with a detailed reading list. In addition, you may want to find out if your local county extension service or state energy office knows of any operating digesters in your area. Talking with individuals who actually have a biogas system, finding out how the system fits into their operation, and how reliable and economical it is, will give you a much better idea of what is actually involved with operating a system.

At the same time, you may want to begin evaluating the resources, energy use patterns, and environmental considerations of your particular operation. Chart I will not provide any conclusive evaluation of the applicability of biogas production on your ranch or farm, but it will help you gather the information you need to evaluate it.

This form will also save you time and money if you should decide to hire a professional engineering consultant. While consultants can be expensive, they often can save you valuable time and resources if you're considering a biogas system.

Biogas production is not appropriate for all situations, but should a detailed analysis indicate some real advantages if it were applied to your particular farm or ranch, you may find that turning a waste problem into a valuable resource is not the contradiction it may have seemed at first.

There are many benefits to be derived from installing a biogas-producing system, but there are also certain liabilities. Although simplified, this chart helps define both the system's strengths and weaknesses.

BENEFITS

1. *Provides pollution control.*
   a) Reduces odor and fly problems associated with storing or spreading raw manure; and
   b) Destroys most harmful bacteria in raw manure which otherwise can pollute ground and surface waters if it is spread on the fields.

2. *Creates usable gas.*
   a) The biogas can be used to offset the cost of operating a manure handling system;
   b) The gas can be used to supplement the energy needs of the farm; and
   c) The biogas can be used to operate an electrical generator with electricity being used on site or sold to the utility.

3. *Creates usable byproducts.*
   a) The effluent can be used directly from the digester as a nutrient-rich fertilizer;
   b) The solids can be extracted and used as bedding material, feed supplement, or potting soil; and
   c) The liquids can be drawn off and spread on the fields with irrigation equipment, can be used to grow algae, or can be recycled and used as part of the manure handling system.

4. *Provides economic benefits.*
   a) In addition to offsetting energy and fertilizer costs, systems can create products which can be sold, including electricity and potting soil from the effluent; and
   b) Unlike traditional manure-handling systems, biogas production qualifies for energy tax credits.

LIABILITIES

1. *Can be expensive to install.*
   a) Systems can potentially cost many thousands of dollars;
   b) Consultants are often required to design a system, adding to the overall price of the system; and
   c) Requires special storage for the biogas produced.

2. *Can be dangerous.*
   a) If the biogas comes in contact with the air, it can be extremely explosive; and
   b) Digesters, because they contain no oxygen, can also be dangerous to work in. If they require cleaning or repair they must be well ventilated before anyone enters them.

3. *Can be difficult and time-consuming to operate.*
   a) Reaching and maintaining the proper dilutions, pH levels, and ammonia levels can be difficult for a beginner; and
   b) Like a herd of dairy cattle, the system requires daily attention.

CHART I

Whether you hire a consultant to design and/or construct a system, or design and construct the system yourself, you will need to compile the following information. Preparing this information before sitting down with a consultant will save you both time and money.

Size and Nature of Operation

Number of animals by type, weight, and age (i.e., milking cows vs. beef cattle, calves vs. mature cows): ______________
Animals' feed: ______________
Drugs fed or injected: ______________
How animals are confined: ______________

Current Manure Handling System

Amount of manure available daily: ______________
How collected: ______________
How stored: ______________
How disposed of: ______________

Current Energy Consumption and Use

Electricity consumed (kWh/year): ______________
Natural gas consumed (cubic feet/year): ______________
Propane consumed (gallons/year): ______________
Gasoline consumed (gallons/year): ______________
Diesel consumed (gallons/year): ______________
Equipment currently in use that could be converted to biogas:
____

Current Fertilizer Use

Number of acres being fertilized: ______________
Kinds of fertilizer used: ______________
How applied: ______________
Annual costs: ______________

Environmental Considerations

Odor or fly problems: ______________
Environmental or health regulations in force in your area:
____

SECTION II: CASE STUDIES

Several biogas production systems were funded by the Department of Energy's Appropriate Technology Small Grants Program (Section III). The four projects highlighted in this [illegible] vary from small, hand-operated systems (Colonel [illegible] Keel) to large, semi-automatic systems which have since been duplicated in even larger operations (Dr. Edward Fulton [illegible] Bennett). The costs of installing these systems also [illegible] range of possibilities, from an estimated $1,500 for the [illegible] production unit of Colonel Keel's integrated system to the [illegible] required to install a system similar to the one tested at [illegible] State University.

Case S[illegible] Appro[illegible] Techn[illegible] Promot[illegible] Sufficienc[illegible] Farm

Retired Colonel Keel operates a 60-acre cattle ranch which demonstrates the potential for energy self-sufficiency on the farm. His integrated system includes a biogas digester, a solar water heater, a wind generator, and a pickup truck which is converted to use regular gasoline or biogas.

Biogas Production System

1. *Manure Handling*. Manure is collected manually on a daily basis from the field and feeding pen where the twenty cows are kept.

2. *Dilution*. The manure, which usually equals about 40 gallons a day, is mixed with 80 gallons of preheated water before being added to the digester.

3. *Digester*. The digester is a plug-flow type capable of holding up to 3,200 gallons of manure.

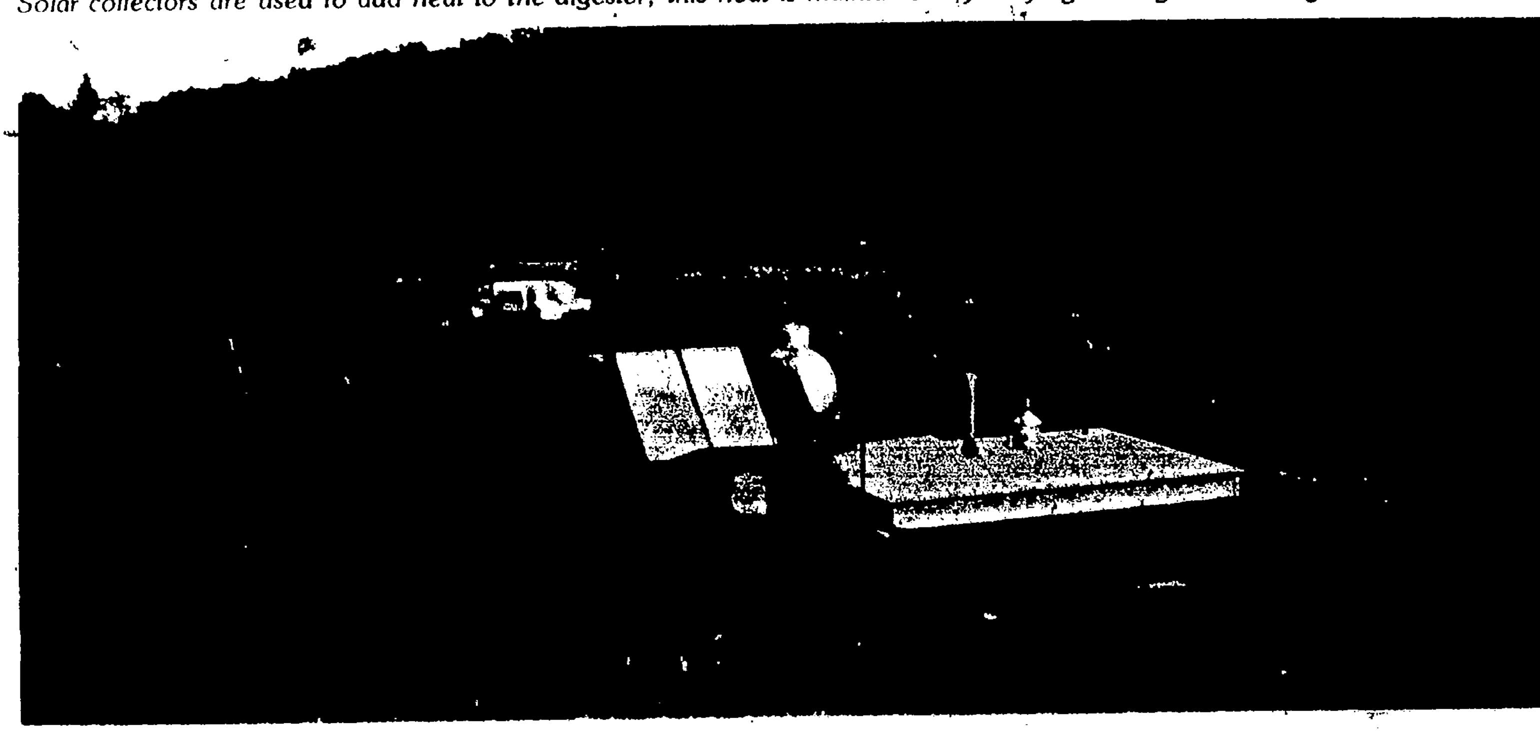
4. *Temperature*. Keel's digester is buried to provide insulation and operates at temperatures ranging from 92°F to 97°F. When temperatures within the digester drop below this range, a thermostat mounted within the digester turns on a solar water heater. Hot water is circulated through the digester via 1-inch pipes.

5. *Scrubbers*. Before storage, the gas passes through a modified propane tank containing a lime-water solution which removes most of the carbon dioxide, and through a recycled oil filter tank containing steel wool which removes most of the hydrogen sulfide. The end product is estimated to be approximately 90 percent methane.

6. *Storage*. The biogas is stored under low pressure in two gas storage tanks. When the tanks are full, the gas is compressed (electricity provided by the 2-kilowatt wind generator) and stored in high-pressure cylinders.

7. *Biogas Use*. The biogas is used to

Solar collectors are used to add heat to the digester; this heat is maintained by burying the digester underground.



provide back-up heat for the solar water heater to fuel a 3 kilowatt generator and, once compressed, it is also used in Keel's pickup which has been converted to use gasoline or biogas

8. Effluent Use. The effluent is removed from the digester, placed in a honey wagon, and regularly spread on the farm's pastures.

Problems Encountered

The biggest problem the grantee encountered when implementing his design for energy self-sufficiency on the farm was finding a manufacturer of vehicle dual-fuel equipment willing to sell to an individual. According to Keel, manufacturers are used to equipping fleets of urban vehicles and suppliers are reluctant to process the request of an individual, particularly in rural areas

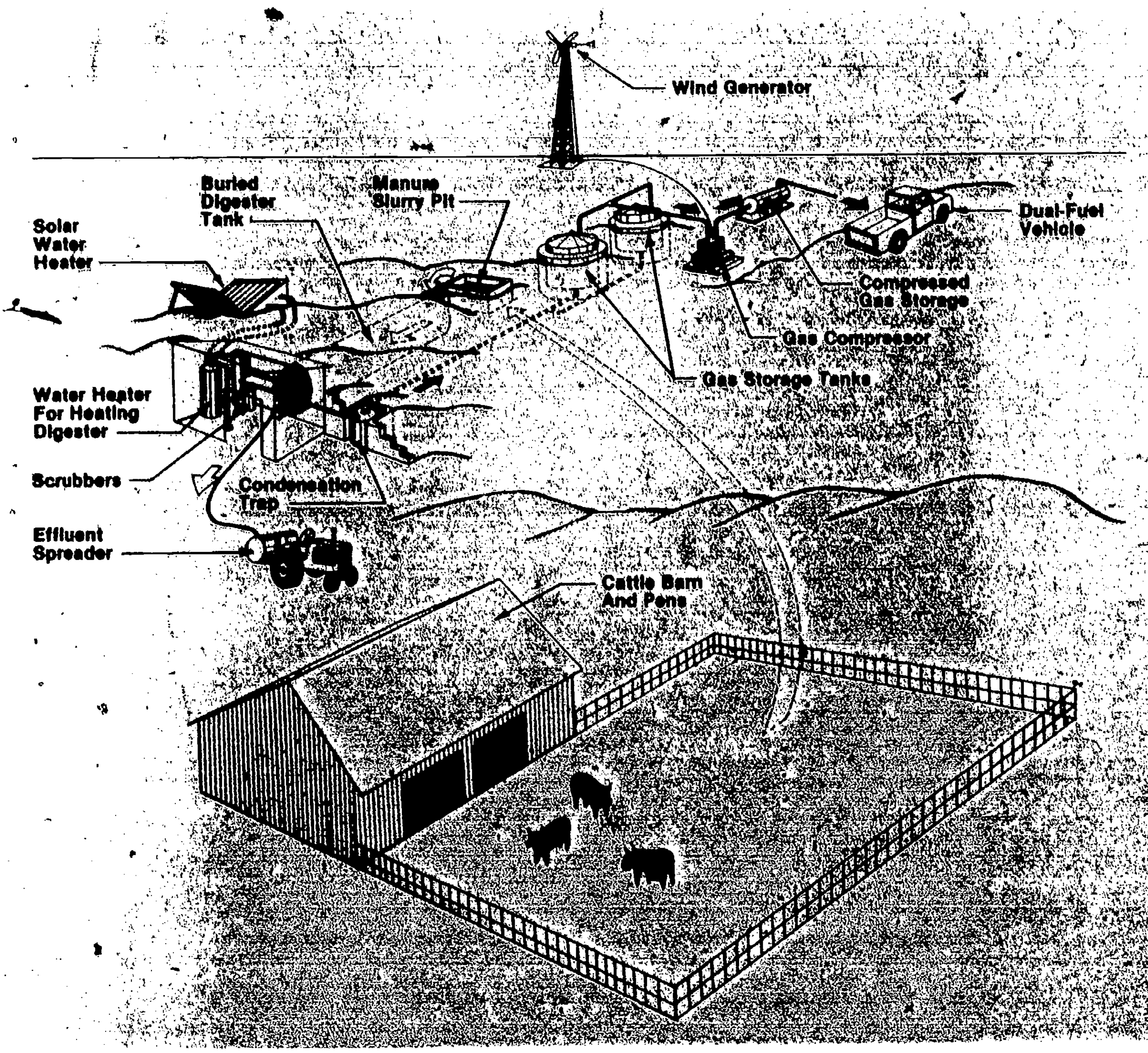
Project Assessment

The main criticism of Keel's project is the price tag. At approximately $25,000, the complete system can hardly be considered cost-effective for an operation of his size without a real manure handling problem. However, Keel estimates that the biogas production portion of his system (i.e., without the wind generator, solar collectors, compressor, etc.) could be duplicated for approximately $1,500, using recycled materials. Keel's project was designed as a small-scale demonstration and he has accomplished what he set out to prove: that even a small farm operation can be relatively energy self sufficient. With only 20 cows, Keel is able to produce 400 cubic feet of biogas a day, enough to keep his operation going. And all of this is accomplished entirely through the use of renewable sources of energy.

For More Information Contact:

Colonel James Keel
P.O. Box 763
Harrison, AK 72601
DOE Contract #:
DE-FG46-79R610947
ATMIS ID: AR-79-002

FIGURE 3: *Keel's System*



Case Study: Rubber D[illegible] Generat[illegible] Biogas [illegible]

In 1978, Michael Weitzenhoff, with the assistance of the University of Hawaii's Agricultural Engineering Department, designed and installed an inexpensive and simple-to-operate plug-flow digester at a small hog farm on Oahu's Waianeae coast. Several problems were encountered in the system's development, including an overflowing digester. That particular problem was solved by replacing the metal tank digester with a large rubber water bag. This novel, yet practical adaptation of the digester is particularly well suited to the warm temperatures of the Islands and has since been adopted by other hog farmers in the vicinity.

Biogas Production System

1. *Manure Handling.* A special holding area, large enough to house 50 hogs, was constructed with slatted floors. The animals' wastes drop through the slats and twice a week they are hosed into collection troughs and pumped into the digester.

2. *Dilution.* Once washed from the holding pens, the manure is approximately 3 percent solids. No additional water is required.

3. *Digester.* The digester is a large rubber, multipurpose bag designed for water or fuel storage. It measures approximately 20 feet by 6 feet and is capable of holding approximately 5,000 gallons of manure.

4. *Temperature.* To maintain a constant operating temperature, the digester bag is partially buried. This "insulation," coupled with the year-round mild temperatures of Hawaii, is enough to keep the operating temperatures at approximately 80°F.

5. *Scrubbers.* Before it is stored, the biogas is passed through an iron "sponge" which removes much of the hydrogen sulfide from the gas. A water trap collector is also used to remove condensed moisture. No attempt is made to remove the carbon dioxide. The biogas has been measured at approximately 75 percent methane.

6. *Storage.* The system produces approximately 500 cubic feet of biogas per day which is collected above the digester and stored in a vinyl reservoir equipped with a water retention seal.

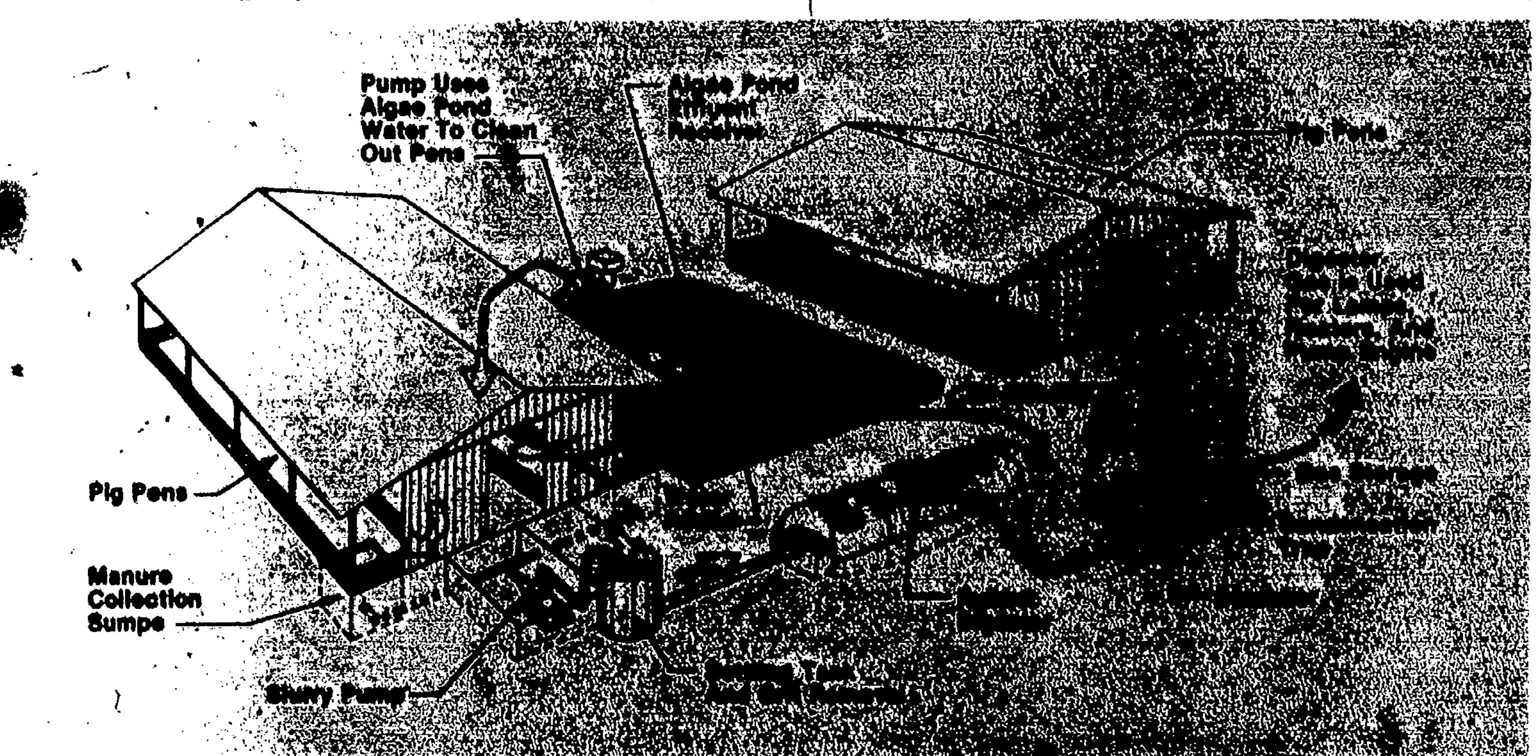
7. *Biogas Use.* Farm equipment that had been fired by propane now burns biogas. This includes the nursery heaters in the farrowing barn, a two-burner gas lamp in the confinement pen area, and the 2-horsepower engine used to pump the algae water for the manure handling system. To use the biogas, the equipment required enlargement of burners and, in the case of the engine, the installation of a butterfly valve in the carburetor.

8. *Effluent Use.* The effluent is channeled from the digester into a 2-foot deep, 20-by-45-foot holding pond which maintains a green color from the algae growth. This water is used to wash the manure into the system which begins the cycle again.

Problems Encountered

The grantee's initial design was not without problems. For example, originally a metal water tank was used as the digester. The island's consistently warm days and cool nights caused the temperature within the digester to fluctuate wildly, and the manure to foam over the top of the tank. This was solved when the grantee discovered the multipurpose rubber bag. Designed for water or fuel storage, the rubber digester was modified with conduits and attached to the piping system formerly used by the metal digester. The new digester was installed partially underground

FIGURE 4: *Weitzenhoff's System*



The rubber digester at the Oshiro hog farm is weighted down with tires to increase gas pressure.

to minimize temperature fluctuations, weighted down with tires to increase the gas pressure, and covered with a black plastic tarp to keep rain water out of the tires to prevent mosquito breeding.

The original system was also designed without a settling basin which required that the digester be emptied and cleaned on a regular basis. With the settling trough, most of the grit and gravel now settles out before it enters the digester bag.

The pond also had problems. High ammonia concentrations from the effluent, coupled with evaporation in the pond, was killing the algae. To keep the ammonia concentration within acceptable limits, water is now added to the pond whenever the water drops below a certain level. In addition, the digester effluent is splashed into the pond to maximize ammonia vaporization.

Project Assessment

Now that the problems have been solved, the system is producing energy which replaces costly propane in the farm operations. It is estimated that the $3,900 investment needed to install this system can be realized in less than two years.

Aside from the economic benefits, the odor and fly problems have been virtually eliminated. And because the farm is located in an area of Oahu which is rapidly becoming suburbanized, it means that the farm will continue to be accepted as a good neighbor.

For More Information Contact:

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M and E Pacific, Inc.
1001 Bishop Street
Suite 500
Honolulu, HI 96813
DOE Contract #:
DE-FG03-78R901912
ATMIS ID: HI-78-009

Case Study: Tarleton State Poultry Production

The Department of Agriculture at Tarleton State University constructed a biogas plant which adjoins their 2,700 hen poultry facility. Although constructed by a university, every attempt was made to operate it under actual ranch conditions. This prototype provided the technical information necessary to design a 30,000-gallon system which was constructed in 1981.

Biogas Production System

1. *Manure Handling System.* Twenty-seven hundred laying hens are confined in a hen house. Their manure falls into a collection trough where it is gathered together and washed into a settling basin. Feathers and hay particles float to the surface and gravel and calcium chips settle to the bottom of the basin. These are both removed before the manure enters the digester.

2. *Dilution.* The chicken manure is diluted with water and mixed at a rate of 2.5 to 1 to reach the desired consistency of 8 to 9 percent solids.

3. *Digester.* The digester consists of a 7,000-gallon horizontal tank. Biogas is pumped into the digester to circulate the processing manure.

4. *Temperature.* Operating temperature is approximately 95°F. This is maintained by circulating biogas heated water through pipes in the digester. The digester tank is also partially buried to provide insulation.

5. *Scrubbers.* Before storage, the gas is passed through iron filings mixed with wood chips which remove the hydrogen sulfide. The final product is estimated to be approximately 60 percent methane.

6. *Collection and Storage.* The biogas is transferred by pipe to a collection tank. When the tank reaches a certain level, the gas is compressed and stored in high-pressure propane storage tanks.

7. *Biogas use.* It is estimated that approximately one-fourth of the 900 cubic feet of biogas produced every day is used to maintain digester

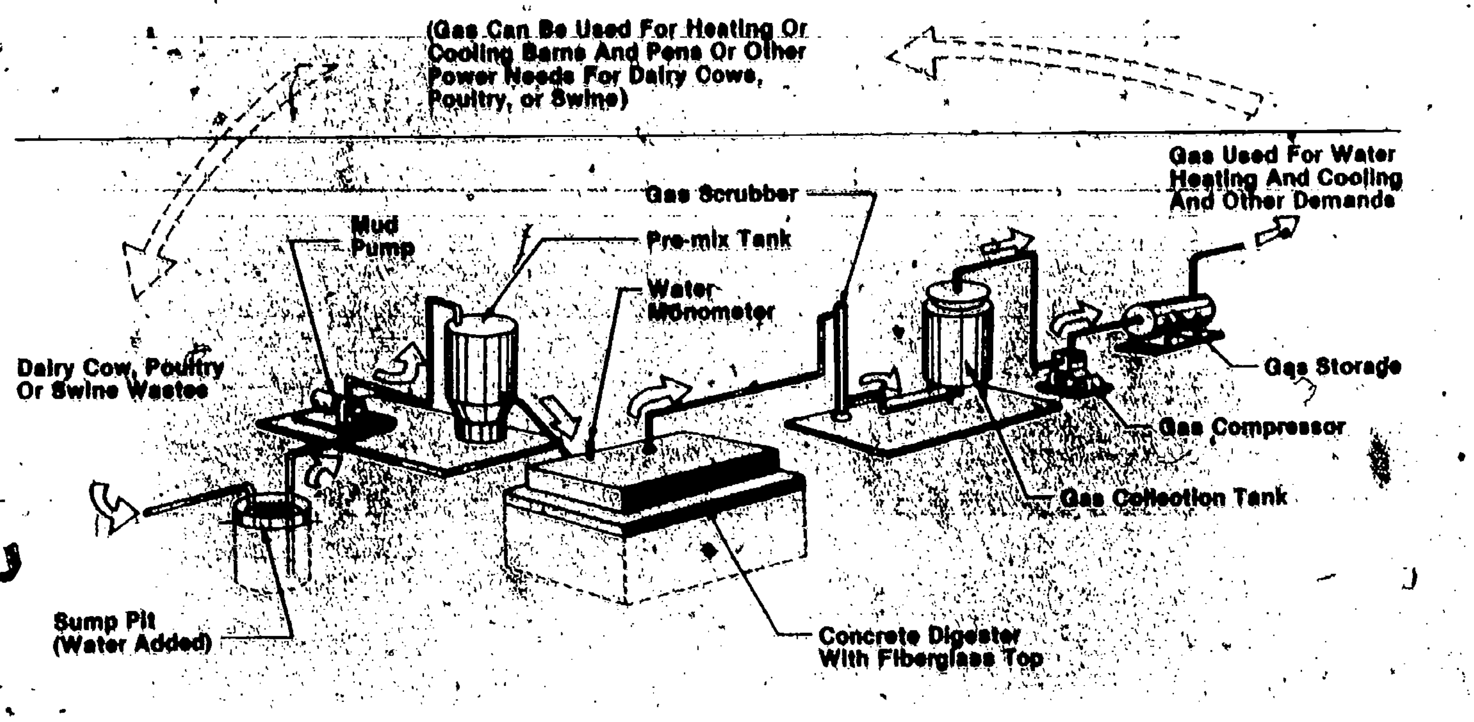


FIGURE 5: *Tarleton State's System*

temperatures. The rest is used to power water heaters for the ranch facility, air conditioners for the chicken coops, and an electrical generator.

8. *Effluent use.* The effluent is daily drained as new manure enters the system, and stored in a pond. The effluent is spread regularly to fertilize the ranch's land.

Problems Encountered

The testing of the prototype biogas system under normal operation conditions helped to identify the day-to-day problems that may have gone unnoticed in a laboratory setting. The biggest difficulties encountered were equipment breakdowns and a lack of understanding about the process by those operating the system. Before the premixing chamber was added to the system, feathers, grit, gravel, and hay formed a hard scum in the digester which inhibited the digestion process and clogged the pipes. Settling basins are essential for efficient operation according to the grantee.

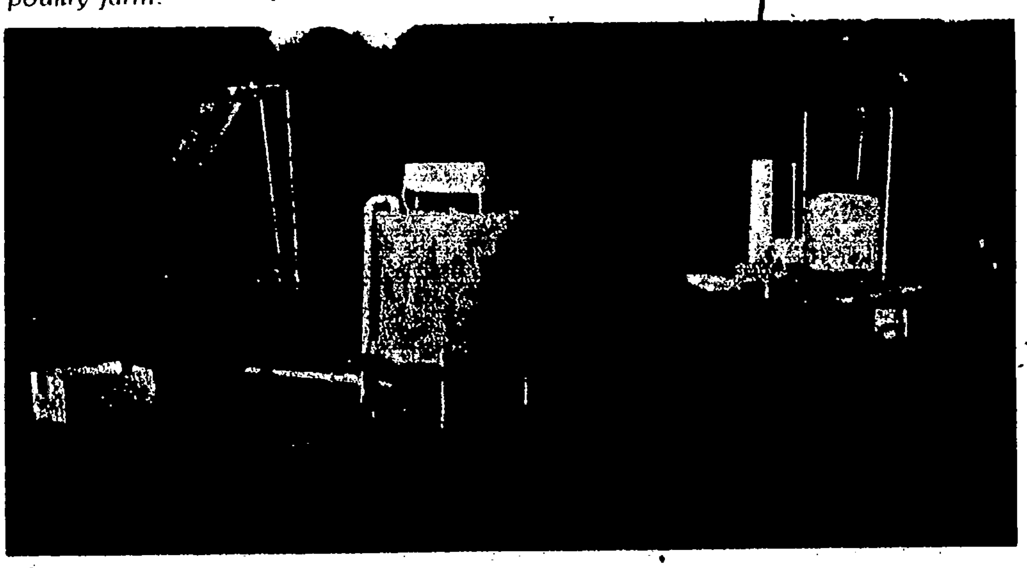
Project Assessment

The system cost over $97,000 to construct, which is not economical for a 2,700 hen operation. However, using the information generated by the project, the University has determined that for about $5,000 more (in 1980 dollars), a similar system could be constructed for a 60,000 bird operation. With tax credits, interest, and depreciation considered, the system should pay for itself in approximately five years from the energy it would produce.

For More Information

Dr. Edward Fulton
Department of Agriculture
Tarleton State University
Stevensville, TX 96402
DOE Contract #:
DE-FG-46-79R610981
ATMIS ID#: TX-79-005

The Tarleton State system provided the technical information necessary to design a similar 30,000-gallon system at a large poultry farm.



Case Study: Dairy Cattle: Electricity the Farm

Bill Hadley and Spencer Bennett, who operate a commercial and agricultural business in Henniker, New Hampshire, designed and constructed a biogas production system on Ken Hadley's dairy farm. The system was the first of its kind in New England, providing an efficient manure handling system and at the same time generating electricity which is sold to the local utility. Hadley and Bennett have since scaled up the design for a farm in Vermont with 350 dairy cattle, and are currently developing a similar system for a 7,000-head cooperative.

Biogas Production System

1. *Manure Handling.* Every day, approximately 1,000 pounds of manure are scraped and hosed from the barn into a mix pit where a chopper/mixer pump feeds it into the digester.

2. *Dilution.* The manure from Hadley's dairy cows is approximately 14 percent solids, therefore dilution is not required. However, cleanup water does get mixed in with the manure before it enters the digester.

3. *Digester.* The digester is a plug-flow type, constructed of concrete, and measures approximately 40 feet by 12 feet by 8 feet.

4. *Temperature.* The operating temperature of 95°F is maintained by preheating the manure before it enters the digester. This is accomplished by dumping the manure over pipes filled with hot water. The water is heated by a heat exchanger attached to the biogas-fired electrical generator.

5. *Scrubbers.* The biogas produced is approximately 55 percent methane and is burned as is, without passing through any scrubbers.

6. *Collection and Storage.* The biogas is stored in a 3,000-cubic-foot PVC bag on top of the digester.

7. *Biogas Use.* The biogas produced is piped directly from the digester to a 12½-kilowatt generator. The waste heat produced by the generator is captured by a heat exchanger and used to preheat the manure.

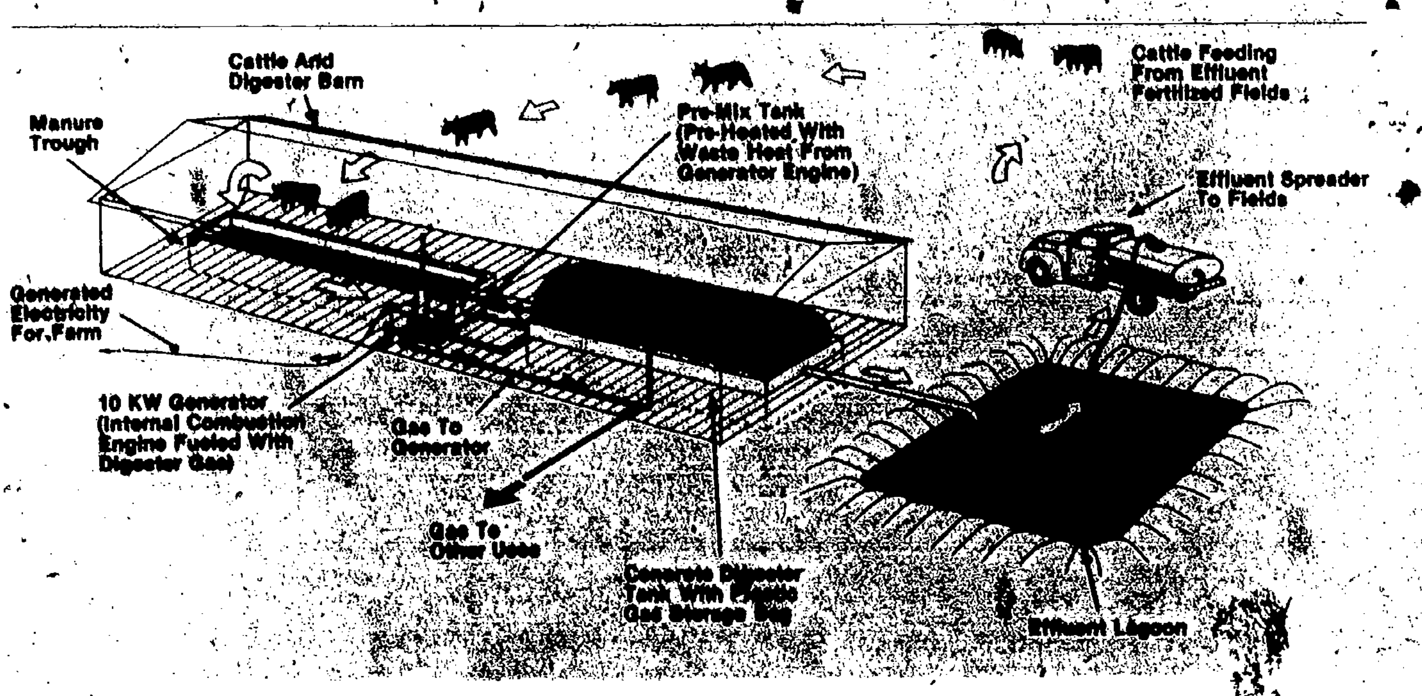
8. *Effluent Use.* The effluent is removed from the digester and stored in a holding pond. Approximately two times a year it is spread on the farmer's fields.

Hadley-Bennett replaced the problem-plagued gravity-flow system with a chopper-mixer pump. But even this needs to be removed from the pit and cleaned regularly

Problems Encountered

Hadley and Bennett's original design included a gravity-flow system which fed the manure from the barn into the digester. Unfortunately, during the winter months the manure was freezing when scraped into the trough, sometimes forming a crust of ice of up to 18 to 20 inches. This problem was alleviated by installing the mixer/pump. But even the pump has not been without problems.

FIGURE 6: *Hadley-Bennett's System*



Nails, rocks, or gravel can work their way into the pit, jamming the pump, requiring that the pump be cleaned on occasion.

Also, the original generator was a recycled 10-kilowatt engine which was operating at approximately 8 kilowatts. This eventually wore out and was replaced by the new, 12½-kilowatt generator which is much more efficient.

Project Assessment

The biogas produced at the Hadley farm averages approximately 60 cubic feet per cow per day, enough to keep the generator operating for 6 to 12 hours. All of the electricity produced is sold to the utility.

The project at the Hadley farm cost approximately $45,000 to construct, and even with tax credits of 35 percent, Hadley and Bennett do not feel that this type of system is cost effective for small operations. Where the system does become attractive is when it is scaled up to meet the needs of larger farms. Hadley and Bennett have since installed a similar system at the Foster Brothers Farm in Middlebury, Vermont. This system recycles the waste from 350 head of dairy cattle and generates approximately 150 kilowatt-hours of electricity per hour, which is sold to the utilities. By investing in a biogas system, the Fosters have, in effect, invested in a manure handling system that is paying for itself.

Hadley and Bennett currently have a new biogas plant on the drawing boards which will process waste from 5,600 to 7,000 dairy cows, producing enough biogas to operate three 350 kilowatt generators. In this system, the effluent will be separated, the liquid used as a fertilizer and the residue cakes used as bedding material for the cows. Even the residue cake will make an economic contribution to the system for, according to Bennett, it is not only superior to sawdust as a bedding material but it is reported to reduce the incidence of mastitis in dairy cows, thereby lowering their vet bills.

[illegible]TION III: WH[illegible] FOR MORE IN[illegible]

DOE Grants Relating To Biogas Production:

The Department of Energy funded several farm size biogas demonstration projects and feasibility studies. The lessons learned by these projects can be extremely valuable to those considering similar systems. Listed below are the biogas grants for which final reports were available as of October 1983. Reports and additional information about all these grants can be obtained from NCAT upon request.

Thomas D. Harris
Auburn, AL
DOE Contract #: DE-FG44-80R410079
ATMIS ID: AL-79-002

The grantee conducted a feasibility study for using biogas production to provide heat, ventilation, and air conditioning. The feasibility of producing biogas from poultry waste is also addressed.

Raymond P. Goebel
Fairfield, CA
DOE Contract #: DE-FG03-81R911613
ATMIS ID: CA-81-011

A pile (102 cu. yd.) of dry dairy cow manure was scraped from a corral, covered by Hypalon (TM), and allowed to produce biogas from July until November. This batch-type fermentation is reported to have produced 18,000 cu. ft of biogas (67% methane) from an estimated 38,000 lb. of volatile solids in the pile (total solids about 50%). The gas yield is reported to be too low (1.53 cu. ft biogas/lb volatile solids) to justify costs at the scale of operation.

Melvin Schefers
Carlyle, IL
DOE Contract #: DE-FG02-81R510293
ATMIS ID: IL-81-005

This grantee attempted to design, build, and operate a poultry waste-to-methane-to-electricity conversion system. Problems reported include: 1) the poultry farm originally selected to house the system burned down; 2) available used equipment limited design options; 3) feathers plugged pumps; 4) the suppliers of the cover for the digester would not guarantee the material would be airtight; and 5) odors. The project was abandoned. The grantee concludes that methane production is not practical on a farm operated part-time.

Hunter S. Barney
Freeport, IL
DOE Contract #: DE-FG02-82R510210
ATMIS ID: IL-80-005

The grantee prepared a report which describes existing facilities of Gilt Edge Farm in Freeport, IL, energy consumption data, the potential for anaerobic digestion, a preliminary recommended system design, and a financial analysis of the design implementation. A single digester system, operated at 35°C is estimated to have a 28.3 percent return on investment if the biogas is used for heating only and a 21.8 percent return on investment if an engine generator is used to produce electricity and the waste heat is collected and used.

R. E. Hasbrook
Ames, IA
DOE Contract #: DE-FG47-79R701008
ATMIS ID: IA-79-009

The grantee attempted to develop a practical effluent-to-influent heat exchanger to preheat wastes going into an anaerobic digester. A plate-type heat exchanger with oscillating fingers was used to provide sufficient agitation for solids suspension. The agitating finger design failed to provide sufficient separation and the design provided inadequate agitation. The grantee suggests air agitation as a possible alternative.

Robert M. Taylor
Bolton, MA
DOE Contract #: DE-FG41-81R123281
ATMIS ID: MA-81-002

This project demonstrates integrated energy production on a small farm. A solar hot water heating system was installed to heat a small calf barn and provide hot water to clean milking equipment. The solar heating system also provides process heat for an on-site methane and fuel alcohol production system. The alcohol produced is used to fuel farm vehicles and the methane is used to heat water.

Anton Potami
St. Paul, MN
DOE Contract #: DE-FG02-81R510316
ATMIS ID: MN-81-008

The Agricultural Extension Service received this grant to conduct educational activities for farmers concerning the use of alternative energy fuels: fuel ethanol, vegetable oils, and farm-produced gaseous fuels. A working model was developed and demonstrated at nine field days throughout the state and a 12-minute, 16-mm movie was produced. The film compared traditional fuels (gasoline and diesel) with alternative fuels. The comparison emphasizes the energy value and power output of the traditional and alternative fuels and briefly describes the engine modifications needed to use alternative fuels.

Dr. Dennis D. Schulte
Lincoln, NE
DOE Contract #: DE-FG47-79R701042
ATMIS ID: NE-79-005

A tumble-mix concept based on a rotating drum (concrete mixer) was used to investigate the technical feasibility of producing biogas from dry feedlot manure. The process was reported to be feasible.

Della Calentine
Seratina, NM
DOE Contract #: DE-FG-80R612019
ATMIS ID: NM-80-003

The grantee designed and installed a small-scale, integrated system which recycles livestock manure. The system includes a greenhouse, algae ponds, and a biogas digester which provides fuel for the grantee's water heater and cookstove.

Jason C. H. Smith
Raleigh, NC
DOE Contract #: DE-FG44-80R10203
ATMIS ID: NC-80-003

The grantee constructed a biogas system to recycle poultry waste. Two half-buried, insulated and heated (to 50°C) synthetic rubber digesters (15 cubic meters for primary and 30 cubic meters for secondary) were connected in series. The waste from 4,000 laying hens (600 kg/day) was fed to the system which operated at a pH of 7.5 to 8.0. Optimal loading rate was reported at 7.5 kg volatile solids per cubic meter per day. The digesters were reported to produce biogas (55% methane) at a rate of 20.6 cubic meters/day. Biogas for digester heating consumed 49.4% of the available gas.

Thomas B. Williams
Middletown, PA
DOE Contract #: DE-FG43-79R306075
ATMIS ID: PA-79-013

This project investigated the feasibility of using manure to generate biogas on a 150-head dairy farm. The feasibility study indicated that the proposed system was not economically feasible.

Frank J. Bertrano
Towanda, PA
DOE Contract #: DE-FG43-79R306073
ATMIS ID: PA-79-001

The grantee attempted to produce methane gas in a 55-gallon drum using cow manure as a feedstock. The methane was burned to drive an alcohol distillation unit and the condenser water was used to heat the methane digester. Two designs were employed, neither accomplishing the desired results. Failure was attributed to the following: 1) the system was too small, 2) the system needed more insulation to reduce thermal losses, and 3) the operation was too labor intensive.

Vincent T. Martinez
Agana, Guam
DOE Contract #: DE-FG03-78R901969
ATMIS ID: TT-78-005

The grantee designed and installed a biogas system which uses pig and chicken manure. The effluent is composted and used to build up the poor soil quality.

Juan Rivera Negron
Bayamon, Puerto Rico
DOE Contract #: DE-FG42-79R205002
ATMIS ID: PR-79-005

A small-scale methane digester was constructed at a farm in Puerto Rico. The unit was charged with farm wastes and human wastes at five day intervals. A remodeling of the unit is expected to increase its efficiency.

SUGGESTED [illegible]

A Chinese Biogas Manual: Popularizing Technology in the Countryside. Arlene Van Buren, ed., Intermediate Technology Publications, Ltd., London, 1979.

This publication is a translation of a Chinese work describing the types of digesters used in China. They are labor intensive systems and can be constructed by hand, using indigenous building materials. This is a good starting manual for those interested in labor-intensive systems.

Bioconversion of Agricultural Wastes for Pollution Control and Energy Conservation, Cornell University, NTIS (TID 27164), Springfield, VA, 1976.

A comprehensive study of the feasibility of generating biogas on dairies with 40 to 100 cows or in beef feedlots of 1,000 head. The feasibility of biogas generation is presented from a technical, economical, and practical perspective. The study concludes that with operations of less than 100 cows, using biogas systems for gas production alone may not be economical.

Demonstration of Biomass-derived Fuels for Integrated Farm Energy, Sumax Corporation, Texas Energy and Natural Resources Advisory Council Energy Development Fund, Report EDF-052, Austin, TX, 1981.

This is a report on the technical and economic feasibility of methane production from swine manure on the Del Valle Hog Farm in Del Valle, Texas. The digestion system is described and the economic viability of using this system in three configurations is presented with a payback period of five to seven years. The case study is from a farm raising 100,000 pounds of hogs yearly.

Methane Digesters for Fuel Gas and Fertilizer, John L. Fry and Richard Morrell, New Alchemy Institute, Newsletter #2, 1973.

A good basic introduction to biomass digesters and their working components. Included are plans for two models that can be built by the novice to gain a working knowledge of the digestion process. This booklet includes a generalized history of biogas production and a biological description of the digestion process.

Methane Generation from Livestock Wastes, Don D. Jones, John C. Nile, and Alvin C. Dale, Cooperative Extension Service, West Lafayette, Indiana, 1980.

A 12-page brochure that includes a general description of biogas production and a checklist to help the prospective user determine the feasibility and economics of a 100-cow capacity digester.

Methane: Planning A Digester, Peter-John Meynell, Prism Press, Dorchester, England, 1976.

A general overview of the digestion process, the benefits of water pollution control, and odor and pathogen removal. Safety considerations, gas use, and uses for the sludge are also discussed. Provides a guide to planning a digester and how to use it once constructed.

Methane Production from Waste Organic Matter, David A. Staffer, Dennis L. Hawke, and Rex Gordon, CRC Press, Inc., Boca Raton, FL, 1980.

This fairly technical work describes the biology, engineering, economics, performance controls, and mechanics of methane digesters. An introduction to the technology is followed by a survey of digesters around the world, and an overview of the biochemistry of the anaerobic reaction. Hints are provided on digester design, as well as a discussion of operational problems and the environmental conditions necessary for the digester to function. It discusses the potential of several specific feedstocks, and the added potential of digestion for fertilizer production and pathogen removal from organic wastes.

On the Farm Methane, Biogas of Colorado, Inc., South Dakota Office of Energy Policy, Pierre, SD, 1980.

This is a compendium of information that was written to accompany a workshop provided for the South Dakota Energy Office by Biogas of Colorado, Inc. The book describes biogas generation in an easy-to-read style with anecdotes from the author's experiences.

The Do's and Don'ts of Methane Gas Production for Self-sufficiency, Al Rutan, Rutan Publishing, Minneapolis, MN, 1979.

This is an account of one man's experiences with methane digestion. It includes some valuable advice for anyone considering the construction and operation of a small-scale digester.

Methane Generation by Anaerobic Fermentation: an Annotated Bibliography, Christina Freeman and Leo Pyle, Intermediate Technology Publications Ltd., 9 King Street, London, England WC2E84N, 1977.

A critical review of the literature with particular reference to small scale and rural applications. The bibliography is intended for people directly involved in third world type applications, including the building, designing and improving of methane generators.

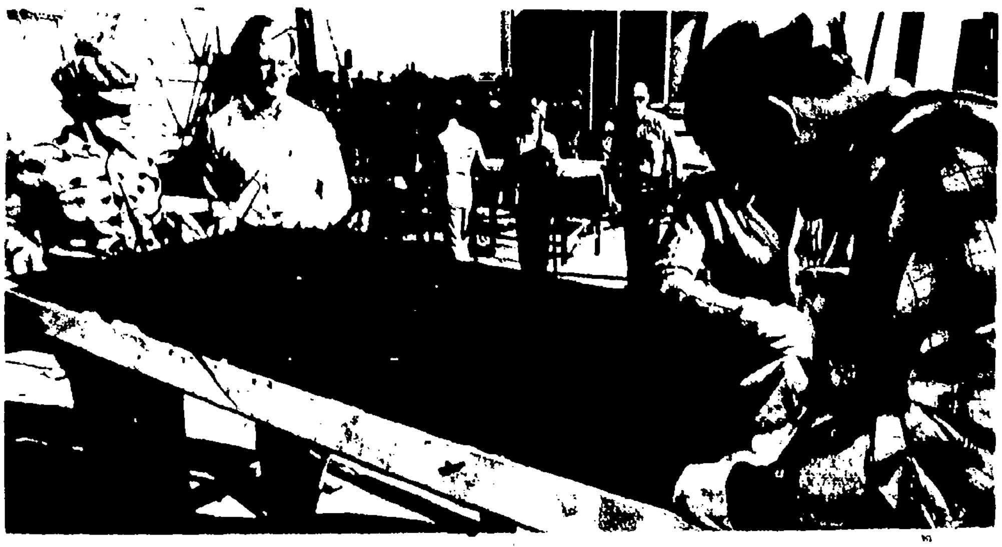
Bibliography of Anaerobic Digestion, Tom Abeles, David Freedman, David Ellsworth and Luc DeBaere, Oasis 2000, University of Wisconsin Center - Barron County, Rice Lake, Wisconsin 54868, EPA Final Report, #R-804-457-010, June 1978.

A compendium-generated bibliography, covering research in anaerobic digestion, divided into eleven major topic areas, with particular emphasis on anaerobic digestion of farm animal manures.

Anaerobic Fermentation of Agricultural Residue: Potential for Improvement and Implementation, Final Report, W.J. Jewell, et. al., U.S. Department of Energy, HCPT/2981-07. National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia, 1978.

This report contains the results of a one-year study by a multidisciplinary team at Cornell University for the U.S. Department of Energy. The study objectives were to identify simple and low-cost anaerobic fermentation design criteria appropriate to small agricultural operations. A simple reactor design utilizing an unmixed plug flow concept was shown to be comparable to a more complex mixed reactor when using dairy cow residue. This is a fairly detailed and technical report for those wishing to delve more deeply into the technology.

LEARN FROM EXPERIENCE



From 1978 to 1982 the U.S. Department of Energy provided about 2,200 grants to a cross-section of Americans with good ideas for saving energy. Their projects reveal how a broad range of appropriate technologies actually work -- from the farm to the country's largest cities.

Their experiences have been examined and presented in a series of thirteen informative publications. Your State energy offices have a limited number of these publications available without charge. Additional copies are on sale at U.S. Government Printing Office Bookstores near you.

APPROPRIATE TECHNOLOGY AT WORK: Outstanding Projects Funded by the U.S. Department of Energy Appropriate Technology Small Grants Program (1978-1981).

Highlights twenty of the many success stories that are found in the DOE grants program.
GPO 061-000-00608-7

WASTES TO RESOURCES: APPROPRIATE TECHNOLOGIES FOR SEWAGE TREATMENT AND CONVERSION

Presents background information on conventional and alternative sewage treatment in the United States and the key issues facing municipal sewage managers.
GPO 061-000-00611-7

DRYING WOOD WITH THE SUN: HOW TO BUILD A SOLAR-HEATED FIREWOOD DRYER

Shows the over 14 million firewood users in America how to build an efficient low-cost firewood dryer and contains suggestions for more efficient burning of the dry wood.
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MOISTURE AND HOME ENERGY CONSERVATION

Focuses on detecting moisture problems in the home and how to correct them and includes a training supplement on how to conduct a moisture audit in a home.
GPO 061-000-00615-0

PHOTOVOLTAICS IN THE PACIFIC ISLANDS: AN INTRODUCTION TO PV SYSTEMS

Helps teachers, adult educators, and community leaders in the Pacific Islands explain the basic parts of a PV system.
GPO 061-000-00616-8

USING THE EARTH TO HEAT AND COOL HOMES

Provides a guide to using the earth as a readily available, low-cost resource for space heating and cooling with a focus on installation, economics, reliability and performance of systems utilizing low-grade geothermal energy and earth-tempered air systems.
GPO 061-000-00620-6

INTRODUCING SUPPLEMENTAL COMBUSTION AIR TO GAS-FIRED HOME APPLIANCES

Shows consumers and building trades people how to increase heating system efficiency by using outside or supplemental combustion air and also includes a set of basic how-to instructions to allow consumers to build necessary ducts and vents. Code and safety implications of these actions are thoroughly addressed.
GPO 061-000-00621-4

SOLAR GREENHOUSES AND SUNSPACES: LESSONS LEARNED

Focuses on the experiences of hundreds of DOE grantees who designed and built greenhouses, and examines individual greenhouse components, including framing, glazing, storage, ventilation and control mechanisms.
GPO 061-000-00622-2

HEAT-RECOVERY VENTILATION FOR HOUSING: AIR-TO-AIR HEAT EXCHANGERS

Teaches owner builders, building trades people, and designers how to size ventilation systems for energy efficient housing. Major emphasis is placed on the air-to-air heat exchanger.
GPO 061-000-00631-1

MAJOR ENERGY CONSERVATION RETROFITS: A PLANNING GUIDE FOR NORTHERN CLIMATES*

Contains state-of-the-art strategies for the builder, architect, and skilled homeowner in deciding the most cost effective procedures for insulating roofs and walls. This decision making manual allows users in northern climates to determine the most cost-effective means for increasing the thermal efficiency of their specific building envelope.

HOME MADE ELECTRICITY: AN INTRODUCTION TO SMALL-SCALE WIND, HYDRO, AND PHOTOVOLTAICS

Introduces the use of wind, water, and the sun as electricity producers and, based on the experiences of grantees, helps the reader make a realistic appraisal of these systems.
GPO 061-000-00630-3

WINDOW INSULATION: HOW TO SORT THROUGH THE OPTIONS

Focuses on the major decision and problem areas with the technology including choosing the right design for the window, how to choose a workable installation method, and how to size up your window-insulation needs given climate, cost, and home orientation.
GPO 061-000-00632-0

AN INTRODUCTION TO BIOGAS PRODUCTION ON THE FARM

Introduces farm-size biogas production and includes a brief discussion on how to evaluate the biogas production potential of a specific ranch or farm.
GPO 061-000-00633-8

***(Will be available by March, 1984)**

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